DARPA Grand Challenge 2005
Technical Paper for

FLYING
FOX

Autonomous
Vehicle Systems

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Abstract

This technical paper provides a high level overview of the Flying Fox autonomous vehicle system. Discussion of key aspects of the system, including vehicle description, actuation, computational processing, localization, environmental sensing, vehicle control and system testing, are described within. This paper is prepared for compliance with the DARPA Grand Challenge qualification process.

1.0 Vehicle Description

1.1 Vehicle Platform

The vehicle platform for the Flying Fox autonomous system is a 1987 AM General M998 HMMWV (Humvee). The vehicle was originally in service with the US Marine Corps, and was purchased as surplus and rebuilt from the ground up. It has been used for extensive personal off-road use for several years.

The vehicle remains in its stock configuration with no structural changes. All components added to the vehicle attach using existing vehicle hard points. The only modifications to the original vehicle platform are:

- Replaced the stock 60A alternator with a Prestolite 200A (5kW) alternator to supply power for additional electronic components
- Spliced to existing vehicle wiring to provide engine health monitoring as well as autonomous control of the start/run system
- Additional batteries for extended pause periods

The vehicle is fully human drivable despite modifications for autonomous operation.

1.1 Actuation System

A photo of the driver portion of the actuator system is shown in Figure 1.1.

Steering is controlled by a servo motor and controller, which directly drives the steering column at the steering wheel attachment. Feedback is provided by integral hall sensors/encoders in the motor as well as a SpaceAge Control position sensor for absolute position feedback.

Throttle is controlled by a linear actuator which directly drives the gas pedal. Feedback is provided by a potentiometer in the linear actuator as well as a position sensor (located in engine compartment) for absolute position. Throttle actuation allows for both human or autonomous operation (whichever pushes the most wins). A manual switch allows the actuator to be released to override autonomous actuation.

Figure 1.1. Flying Fox Actuation System

Primary brake actuation is provided by a linear actuator that attaches to the steering actuation frame and directly moves the manual brake arm. Feedback is provided by a potentiometer in the linear actuator as well as a position linear potentiometer for absolute position.

An emergency braking system is provided by an air cylinder actuator which directly drives the brake arm. This system is designed to fail in the fully depressed position (active electric current is required to release the actuator). It operates strictly in a on-off position.

Brake actuation allows human, primary, or emergency braking (whichever pushes the most wins). Either actuator can be released with a manual switch to override autonomous actuation.

Transmission actuation is provided by a linear actuator that attaches to the transmission shifter. Feedback is provided by a potentiometer in the linear actuator. Actuation allows the vehicle to move in the forward or reverse directions. A pull pin allows the actuator to be disconnected for manual driving.

Relay control provides control of engine start and run operation. The engine can be fully controlled by the autonomous system. The manual start run switch is still operational for manual operation. Kill switches located external to the vehicle as well as on a switch bar next to the steering wheel provides the ability to manually override autonomous engine control.

Relays also provide control of the warning system (strobes and siren).

DARPA's E-stop system is fully integrated into this relay control system. A jumper can be place on the control box to allow bypass of the DARPA E-stop system (as used prior to receipt of the DARPA system).

2.0 Autonomous Operations

2.1 Processing

A photo of the vehicle processing system is shown in Figure 2.1. The majority of processing is performed by our VAMPIRE (Vehicle Autonomous Management Processor In Realtime Environment) chassis. The chassis is a custom design provided by SBS Technologies. It consists of eight conduction cooled 1.8 Ghz CompactPCI processors mounted in a conduction cooled rugged chassis. The chassis is designed to handle the temperatures, shock and vibration beyond those expected in the Grand Challenge.

Additional processing is provided by a dual processor 3.4 GHz workstation. This processor is dedicated for vision based guidance of the vehicle.

The VAMPIRE chassis runs the QNX real time operating system, and the vision processor operates under Linux. All interprocess communication is handled by NDDS provided by Real Time Innovations.

A functional block diagram of the processing system is shown in Figure 2.2. All internal vehicle communication is provided via an internal Gigabit Ethernet switch located in the VAMPIRE chassis. External communication is provided through the addition of a WiFi router and telemetry system, provided by Teletronics. Per the DARPA Grand Challenge rules, the telemetry system is removed for the DARPA NQE and GCE.

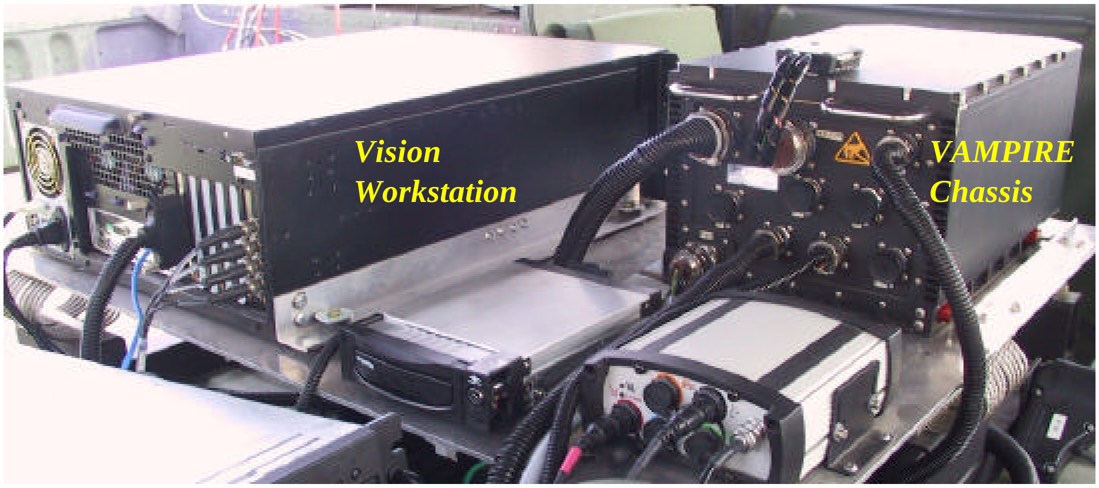

Figure 2.1. Flying Fox Processing System

2.2 Localization

Primary navigation is provided by a NovAtel ProPakLB+ DGPS system. The system uses OmniSTAR HP commercial correction services to achieve decimeter level accuracy.

Supplementary navigation is provided by a system of accelerometers, gyros, magnetic compass and wheel odometry to supplement the primary navigation system. System accuracy with total loss of primary navigation is less than 5% of distance traveled from last known position.

A limited amount of mapping information is combined with the RDDF supplied prior to the start of a run. This modified information is loaded into the vehicle system prior to system start.

2.3 Sensing

Environmental perception is achieved by a combination of vision, LADAR, ultrasonic, and contact sensors.

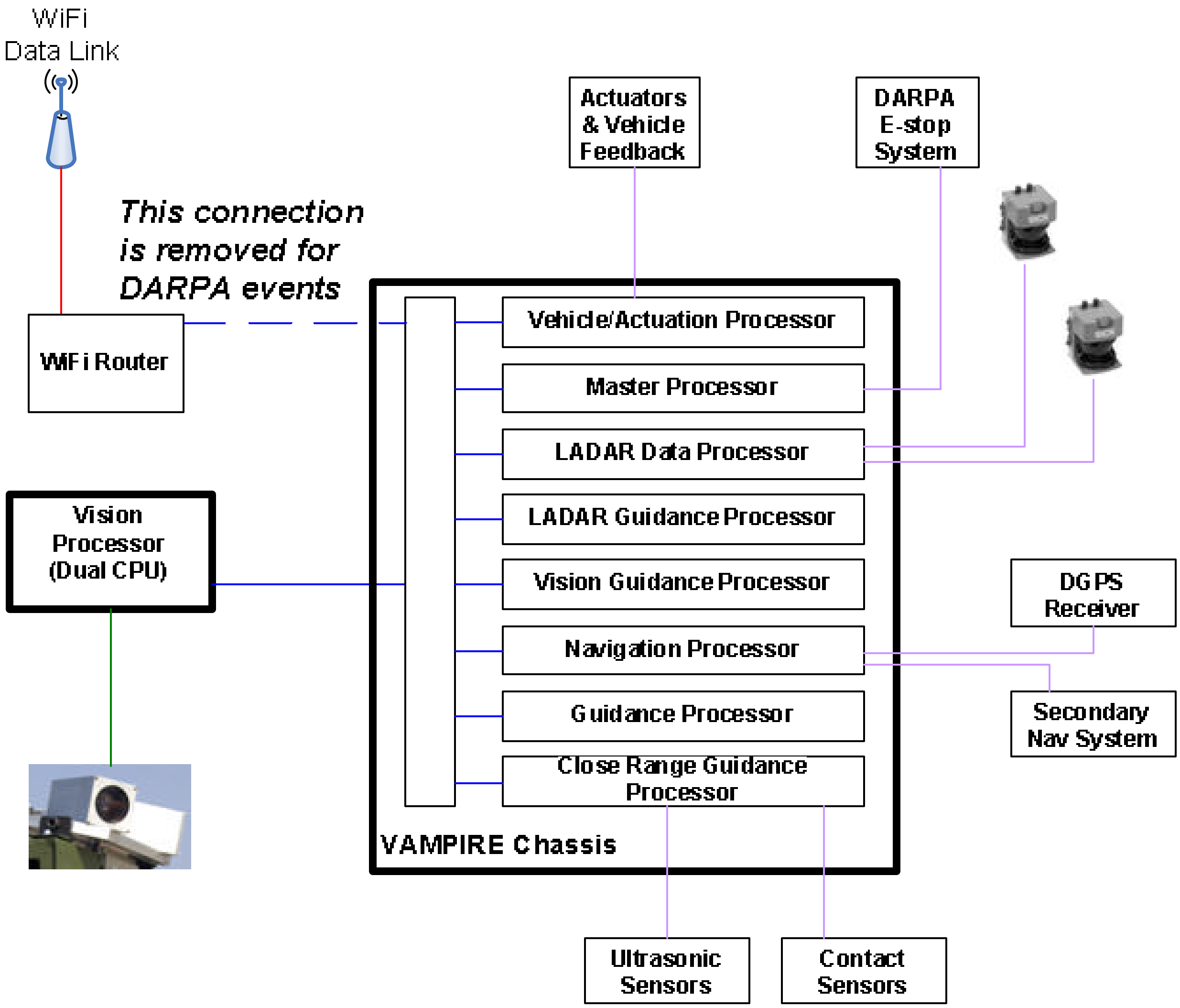

Figure 2.2. Functional Block Diagram

The vision system consists of two cameras oriented to provide nearly 180 degree field of view. Camera effective range is up to 200m. The cameras internally compensate for vibration and varying lighting conditions. Eltron Engineering provided the cameras and custom housings, Active Silicon provided the video capture cards.

The LADAR system consists of two SICK LMS291 units, one integrated into the front bumper and one mounted below the cameras in front of the windshield. These provide up to 180 degree field of view with a range of up to 80m. A custom designed vibration isolation system is installed on the bumper mount unit.

Ultrasonic sensors are located fore and aft to supplement close range (up to 2m) obstacle identification. They are located within the front brush guard.

Contact sensors are integrated into the front brush guard to provide a method to indicate whether vehicle is in contact with an immoveable obstacle. They are tuned to only respond to solid, impassible obstacles (i.e. brush and other soft objects will not trigger the sensors).

Sensing architecture is fused with the overall vehicle control. Primary sensing guidance is performed by the vision system. If any other sensor subsystem indicates that obstacles are present, then that sensor subsystem overrides the vision system.

Vehicle state sensing is achieved through existing vehicle sensors to monitor vehicle and engine health. Vehicle state is also derived from the supplementary navigation system that provides vehicle orientation with respect to the flat earth. Feedback is also provided by several sensors located with each actuation system.

Corridor boundaries and restrictions (derived from the supplied RDDF file) are an integral part of the sensor based guidance systems. The system outputs provide an optimum speed and steering command for vehicle control based on the perceived environment.

Steering commands are used to directly control vehicle steering. Speed commands, coupled with vehicle pitch and roll, are used to determine the desired throttle and brake position.

2.4 Vehicle Control

The system does not use waypoint following/capture logic. The system continuously monitors its position with respect to the allowable corridor. Should the vehicle violate the allowable corridor, software will determine the best course of action to correct the situation (reverse course or make small forward corrections to get back in bounds).

Vehicle stuck scenarios are handled through close range sensors (ultrasonic, LADAR & contact sensors) if stuck against immobile obstacles as well as vehicle wheel rotation with respect to other navigation clues for mud/sand/high-center obstacles. Flying Fox is capable of forward and reverse operation.

If any external sensor determines there are obstacles within the corridor boundary, these guidance routines will override the default vision system for vehicle control.

Speed control determines the need for braking and throttle actuation. This system already takes into account vehicle pitch and compensates for starting/stopping/operating on flat and inclined surfaces.

Navigation and sensing information are integral to one another. The sensing based guidance routines will not suggest steering/speed commands that will violate the allowable corridor.

The vehicle is fully operational for human driving. A key switch, located next to the steering wheel, provides the ability to switch between Autonomous, Remote Operation, and Manual modes. Remote Operation is disabled for the DARPA NQE and GCE. In Manual mode, the driver has full control of the vehicle (all autonomous control is disabled). The switch bar also provides override switches for each actuator for partial autonomous operation while still in Autonomous mode or for overriding stuck actuators for system failures. The only control that is not overridden by the console switches is the transmission. This can be easily overridden with a pin pull on the transmission actuator which allows the actuator to move freely by hand.

Figure 2.3. Manual Overrides

2.5 System Tests

Where feasible, each component was tested separately before integration into the actual autonomous system. Unit testing greatly minimized issues when integrated into the autonomous system.

Full system testing was performed on terrain typical to be encountered during the NQE and GCE. A majority of testing was performed in dirt construction lots (in close proximity to vehicle storage location) or in representative desert testing locations throughout Southern California. Since many team members have extensive experience with off-roading in the deserts of Southern California, we found it easier to actually test the vehicle over representative terrain rather than try and simulate this.

As expected in any prototype system development project like this, as the design of the autonomous system has evolved an assortment of hardware and software problems have presented themselves. As mentioned previously, a majority of these were addressed at the component level before integrated into the vehicle. Some problems cannot be determined individually, especially when dependent on the interaction of multiple components or problems created from operation over realistic terrain. Fortunately, our test approach has been to test early and often in the development cycle. This has provided us plenty of opportunities to catch problems that arose early and apply corrective action prior to the DARPA Grand Challenge events.

Incremental testing will continue on the autonomous system throughout the remaining time leading to the DARPA Grand Challenge.